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Developing methodology to evaluate eye lens dose for medical staff: preliminary results

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Abstract: Due to epidemiological evidence on the increasing incidence of cataracts in interventional cardiologists, the ICRP has recommended reducing the eye lens dose limit from 150 mSv/year to 20 mSv/year. Thus, the current status of occupational dose assessment for healthcare workers shows that it requires more precise measurements of eye lens dose. We investigated dosimetric characteristics of OSLD nanoDot and InLight type by using a multi–filter technique to determine the average air kerma of the incident beam and other essential dosimetric factors such as the relative energy responses and conversion coefficients from the air kerma to personal dose equivalent operational quantities Hp(d). Based on assessing and analyzing factors that influence Hp(d), the methodologies were developed to evaluate eye lens dose for medical staff, especially high-risk subjects such as interventional physicians. The results show that 3 methods to evaluate eye lens dose have been deployed in the cardiovascular intervention department: directly by nanoDot dosimeter, indirectly by personal dosimeter (InLight), and quick method based on the relationship with exposure duration. It was found that one interventional cardiologist exceeded the dose limit of 20 mSv/year for eye lens dose without protective measures. In other words, the risk of cataracts is possible when the cumulative dose for 30 working years is considered.

Keywords: *OSLD, eye lens dose, personal dose equivalent quantities Hp(d).*

I. INTRODUCTION

According to survey data from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [1] in 57 countries, approximately 24 million interventional radiology procedures are performed annually with an average frequency of about 3.2 procedures per 1000 population. The effective dose in interventional radiology can be up to 15 mSv per procedure for percutaneous coronary intervention (PCI),

Table I. Standard reference doses of common cardiological examinations [4]

Diagnostic produres	Effective dose (mSv)	Equivalent number of PA chest (each 0.02 mSv)
CONVENTIONAL RADIOGRAPHY		
Chest X – ray (PA)	0.02	0.008
INVASIVE RADIOLOGY		
Diagnostic coronary angiography	7	350
PCI	15	750
Dilation chronic coronary occlusion	81	4050
Arotic valvuloplasty	39	1950
Abdominal angiography or aortography	12	600

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which is equivalent to 750 routine chest X–rays. The results of several studies on occupational exposure for interventional radiology (IR)/interventional cardiology (IC) staff showed that, in addition to skin redness and cataract genesis, there is also an increased risk of brain tumors (especially tumors on the left side of the brain) [2,3].

In a publication in 1991, the International Commission on Radiation Protection (ICRP) [5] recommended the annual equivalent dose limit to the eye lens of 150 mSv/year and a threshold dose of 0.5 – 2 Gy for posterior subcapsular cataracts (PSC) and 5 Gy for visual impairment. Subsequent studies have shown that cataracts may occur at a lower dose or no threshold. Thus, the ICRP proposed a new dose limit for eye lens of 20 mSv/year (averaged over defined periods of 5 years; the dose should not exceed 50 mSv for any year). This recommendation has been agreed upon by international organizations such as the International Atomic Energy Agency (IAEA), the Health Protection Agency (HPA), and the European Atomic Energy Community (Euratom).

When the new dose limits are in force, more direct and accurate dose assessment devices should be required. Because the new dose limits could be breached for physicians performing hundreds of procedures annually, especially continuous improvement of technology to meet the treatment needs of more complex cases has raised concerns about the possibility of increasing patient dose and occupational dose.

Most service companies in Vietnam use dosimeters worn at the chest level, above and under the lead apron, to monitor occupational doses for interventional medical staff. However, there are no national technical standard regulations or guidelines for determining occupational eye lens dose uniformly between hospitals. Until now, the data for evaluating eye lens dose in Vietnam have not been published.

For the above reasons, this study aims to develop the measurement methodologies of eye lens dose for medical staff, particularly interventional cardiologists.

II. METHODS OF EYE LENS DOSE ASSESSMENT FOR MEDICAL STAFF DURING IR/IC PROCEDURES

A. Risk of occupational diseases for medical staff practicing IR/IC procedures

Many studies have shown that interventional staff conducting fluoroscopy–guided procedures receives the highest occupational eye lens dose among all medical staff. Compared to other diagnostic teams, such as CT or X–rays, the interventionist must always be near the patient while the beam is on, so it is difficult to avoid exposure from scattered radiation. Eye lens dose for each

Tab. II. Eye lens dose in IR procedures [6]

Procedure	Eye dose (mSv)	
	Unshielded	Shielded
Hepatic chemoembolization	0.270 – 2.140	0.016 – 0.064
Iliac angioplasty	0.250 – 2.220	0.015 – 0.066
Neuroembolization (head, spine)	1.380 – 11.200	0.083 – 0.329
TIPS creation	0.410 – 3.720	0.025 – 0.012
CA and PTCA	0.294	0.013
EVAR	0.010	

interventional procedure (Tab.II) may vary depending on the role and expertise.

Procedures not optimized, malfunctioned equipment, frequently repeated procedures, or complex circumstances can expose medical staff to a higher level of radiation than usual. Furthermore, the cancer risk is a random process in which radiation risk increases with cumulative radiation. According to the recommendations of the Swiss Society of Radiobiology and Medical Physics [7], eye lens dose must be regularly monitored when it exceeds 6 mSv/year.

In the past, ionizing radiation-induced cataracts were considered a deterministic effect, with a threshold dose of 5 – 8 Gy for chronic exposure, and 1 – 2 Gy for acute exposure (ICRP 60, 1991) [5]. The studies of radiation-induced cataracts in atomic bomb survivors and Chernobyl clean–up workers found that radiation-induced cataracts can occur at a dose which was much lower than the previously established levels and might occur without a threshold dose. Therefore, after the meeting in April 2011, ICRP proposed to reduce the threshold dose for the eye lens to 0.5 Gy. The recommended dose limit for occupational exposure is 20 mSv/year, averaged over 5 consecutive years, with no year exceeding 50 mSv.

Cataracts and brain tumors are two problems considered when it comes to the effects of ionizing radiation. Cataracts are anatomically classified into cortical, nuclear, and PSC. Common radiation-induced cataracts are PSC.

B. Studies about staff suffering exposure to ionizing radiation

The International Retrospective Evaluation of Lens Injuries and Dose (RELID) [8] was initiated in 2008 by the IAEA to evaluate occupational eye lens dose and associated radiation injury. The study groups included interventional cardiologists and staff. Annual lens doses were estimated, and eyes were examined for the presence of PSC. The RELID revealed an association between PSC and radiation exposure: 38 – 53% of interventional cardiologists and 21 – 45% of staff had detectable PSC. In the RELID survey, the responses of cardiologists from over 56 countries indicate that only 33-77% of interventional cardiologists use personnel monitoring devices routinely. The report of the Society for Cardiovascular Angiography & Interventions (SCAI) [9] has shown that 86% of brain tumors in interventionalists have been located on the left side of the brain. The average radiation exposure on the left side of the head is 4.7 times the dose on the right.

A pilot study at King Chulalongkorn Memorial Hospital, Bangkok (Thailand) [10], monitored the eye doses of 16 interventional cardiology staff (both with and without lead glass). It started in December 2015 and continued for 3 years. The average number of cases per year was1300 for coronary angiography and 700 - 800 for PCI procedures. 4 nanoDot dosimeters were taped on the left and right ends of the lead glass eyewear at the outside and inside of it to evaluate Hp(3), 2 InLight dosimeters in which: the first dosimeter was placed at waist level and under the lead apron for determination of Hp(10), the second dosimeter wasplaced at the collar for determination of Hp(0.07) and estimation of Hp(3). The eye lens dose estimated by 2 InLight dosimeters was 5.700 mSv/year, measured by nanoDot dosimeter was 8.059 mSv/year for the left eye and 3.552 mSv/year for the right eye. Two of 16 interventional cardiologists received annual eye lens doses for the left side without lead glass higher than 20 mSv/year.

The other study evaluated the eye dose of 12 physicians (9 with lead glass, 3 without lead glass) and 11 technicians during cardiac catheterization [11]. The interventional procedure was considered from September 2015 to February 2016, with 1707 coronary angiograms and 902 IC procedures such as PCI. Also, estimate eye lens dose using an InLight dosimeter worn outside the lead apron on the left of the neck. The results showed that no technicians exceeded the equivalent dose limit for the lens (20 mSv/year). One physician who did not wear lead glasses exceeded the equivalent dose limit. The eye lens dose was overestimated when they were measured by a neck dosimeter compared with a direct assessment with an eye-specific dosimeter.

Another study on ionizing radiation effect on brain tumor development [3] was conducted in a group of 23 interventional cardiologists, 2 electrophysiologists, and 6 interventional radiologists. All staff had worked for 12 to 32 years in the catheterization laboratory (cath lab), and their age range was from 49 to 67 years. The most common tumor type was glioblastoma multiforme, identified in 17 cases (55%), 2 cases of astrocytomas (7%) and 5 cases of meningiomas (16%). The more significant number of tumors observed in the left brain than in the right brain reflects a different dose distribution for interventional cardiologists.

C. Measurement methodologies of the eye lens dose

The equipment used in this study includes 2 types of optically stimulated luminescence dosimeter (OSLD): nanoDot dosimeter and InLight one (Fig.1), and Digital Subtraction Angiography (DSA) system – Artis Zee at the Department of Interventional Cardiology.

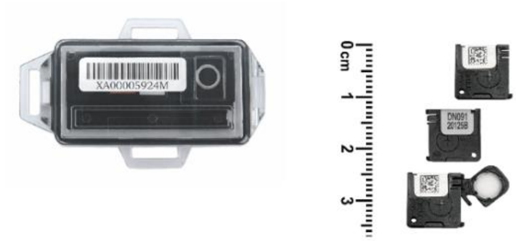

Fig. 1. OSLDs with InLight type (left side) and nanoDot one (right side)

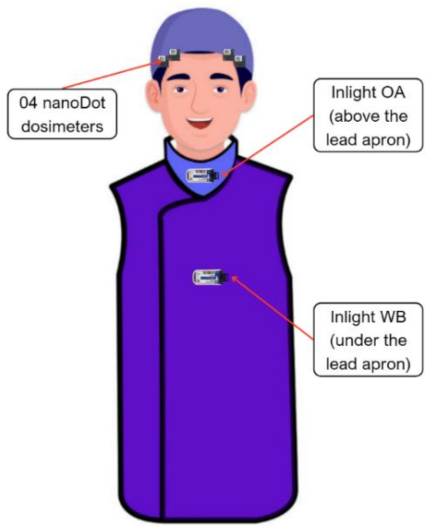

Fig. 2. The setting position of dosimeters

The survey was conducted in 10 weeks (January to March 2023) at the Department of Interventional Cardiology. The dosimeter sets were explicitly coded for each staff (Fig.2): 4 nanoDot dosimeters were worn on surgical scrub hat (near the eyes, 2 dosimeters at the edge of the hat on each side), 2 InLight ones were worn at the chest level (under the lead apron) and on the collar (above the lead apron). Every week, the dosimeters are read with the MicroStar Reader (Landauer Ltd.). Data can be evaluated in three ways: indirectly by InLight dosimeters, directly by nanoDot ones, and by the quick method based on the relationship between eye lens dose and exposure duration.

1. Indirect method of measuring eye lens dose by InLight dosimeter

According to the recommendations of organizations worldwide, to accurately assess eye lens dose, the dosimeters must be attached as close to the eye as possible. Therefore, attaching the InLight dosimeter above and under the lead apron only indirectly evaluates eye lens dose through the algorithm of Landauer Ltd. This method is based on the readings of 4 chips located in 4 positions with different filters of the InLight dosimeter (multi-filter technique) and sets the reading ratios under different filters. Using the algorithm of Landauer Ltd. [11], we can determine the energy E of the beam reaching the dosimeter and the quantities of Hp(10), Hp(0.07) and Hp(3). The eye lens dose was calculated as follows [7]:

a. Using eye lens protective means (goggles, etc.)

By the recommendations of the Swiss Society of Radiobiology and Medical Physics [7], the eye lens dose equals the personal dose equivalent of Hp(0.07). When two dosimeters are worn, one WB dosimeter is worn at chest level under the apron and one OA dosimeter at chest level over the apron, the eye lens dose is equal to the sum of the personal dose equivalent measured with both dosimeters ($H_{total}(0.07)$), by taking into account the Geometrical Correction Factor (GCF) and Dose Reduction Factor (DRF):

$$H_{eyelens} = H_{WB}(0.07) + f_L \times H_{OA}(0.07) \quad (1)$$

$$\left(f_L = \frac{GCF}{DRF}\right)$$

b. No using eye lens protection means (goggles, etc.)

In this case, the eye lens dose was equal to the personal dose equivalent dose of Hp(0.07) as measured by WB and OA dosimeters. Since no protective device is used, the correction factor DRF = 1:

$$H_{eyelens} = H_{WB}(0.07) + f_L \times H_{OA}(0.07) \quad (2)$$

$$\left(f_L = \frac{GCF}{1}\right)$$

2. Direct method of measuring eye lens dose by nanoDot dosimeter

The eye lens dose is calculated using the formula:

$$\begin{aligned} Hp(3) &= K_{air} \times Cp(3) \\ &= CF^E \times (R - R_{BG}) \times Cp(3)\ (mSv) \quad (3) \end{aligned}$$

Where K_{air} is Kerma in the air (Gy), Cp(3) is the conversion coefficient from Kerma to dose equivalent at the corresponding depth of 3 mm (Sv/Gy), CF^E is the calibration factor at energy E, R is the reading of the dosimeter and R_{BG} is reading of background dosimeter.
To determine Hp(3), we need to know the energy of the incident beam to determine the CF^E through K_{air}, and $Cp(3)^E$.

a. Determine CF

Using the results that Landauer Ltd. has calibrated nanoDot dosimeters in 2 standard

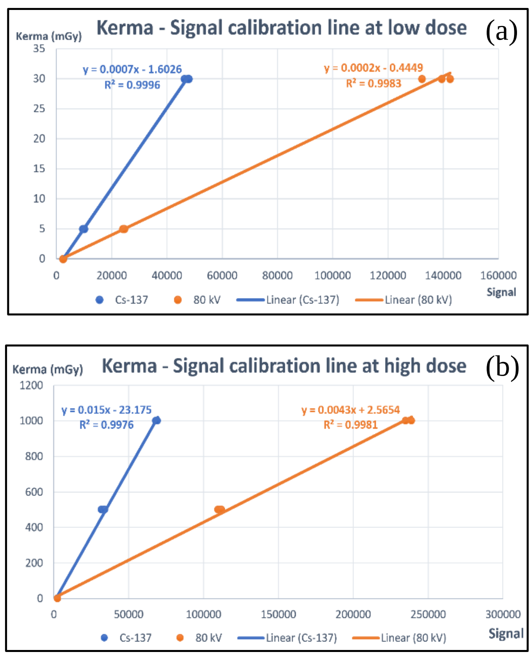

Fig. 3. Landauer calibration lines at low dose (a) and high dose (b)

fields: the X-ray field at 80 kV commonly used in diagnostics, and the gamma field from a source of ^{137}Cs. The calibration Kerma is divided into two modes: low dose mode (0, 5 and 30 mGy) and high dose one (0, 500 and 1000 mGy). From calibration curves, CF^E is determined as Fig. 3.

For low dose mode:

CF (662 keV) = 0.0007 mGy/reading

CF (80 kV) = 0.0002 mGy/reading

For high dose mode:

CF (662 keV) = 0.0150 mGy/reading

CF (80 kV) = 0.0043 mGy/reading

The dosimeters will usually be read at the low dose mode in the range of doses commonly used in personal dosimetry. Therefore:

$$K_{air} = CF^E \times (R - R_{BG}) \quad (4)$$

Where:

CF (662 keV) = 0.0007 mGy/reading

CF (80 kV) = 0.0002 mGy/reading

b. Determine Cp(3)

There are 3 ways to determine Cp(3) as follows:

b.1. It is recognized that usually the X–ray machine operated at the voltage range of 80 – 90 kV for interventional procedures, with a filter of 2 mm Al. This X–ray spectrum can be approximated as a spectrum of the standard radiation field of N80 with an average energy of 65 keV, thereby $Cp(3)^{65keV}$ = 1.66 Sv/Gy (for angle 0^0) according to the data from Table 41 in ISO 4037 part 3.

To recheck the energy determination by X-ray spectrum (Fig.4), we used a dosimeter over the apron and found that the energy calculated by Landauer's algorithm tends to overestimate as compared with the results recorded by the X-ray machine. Thus, the energy results calculated by NTTU algorithm were used. The energy values were in the range of 50 - 60 keV, which is consistent with the above argument.

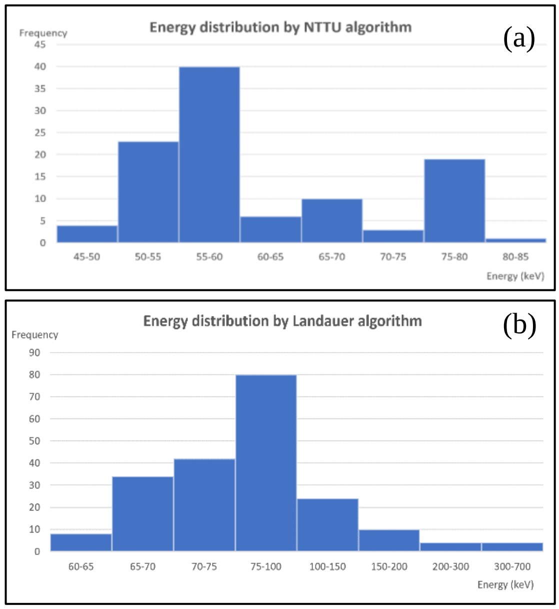

Fig. 4. Energy determined by NTTU (a) and Landauer (b) algorithms for OA dosimeter

b.2. Using the personal dosimeter (TLD, OSLD) to determine the energy of the incident beam can determine Cp(3). In this study, we used OSLD (InLight dosimeter) and assumed that the energy of the incident beam at chest level is the same as in the eye. However, Landauer's algorithm was used while the survey data was being processed, the evaluated energy of the incident beam by Landauer's algorithm was larger than the actual ones. This may affect the accuracy of the determined dose.

Therefore, we are unanimous in using the algorithm NTTU-OSLD of Nguyen Thi Mai Loan and colleagues [13] to calculate the energy of the incident beam approximately. The results show that the energy of the incident beam calculated by NTTU is approximately 62 keV, consistent with the N80 average energy of 65 keV. The conversion coefficient Cp(3) is approximately that of ISO 4037 (Tab.III) [14].

Table. III. Comparison of energy and Cp(3) values according to ISO 4037 with Landauer and NTTU-OSLD algorithms

Radiation source for calibration	Energy (keV)			Cp(3) (Sv/Gy)	
	ISO 4037 [14]	NTTU-OSLD [13]	Landauer [12]	ISO 4037 [14]	NTTU-OSLD [13]
N40	33	33.22	50.33	1.28	1.23
N60	48	46.60	68.67	1.54	1.50
N80	65	61.71	103.17	1.66	1.58
N100	83	80.03	177.67	1.63	1.64
N120	100	95.52	367.17	1.58	1.59

b.3. Using a multi–filter technique for the nanoDot dosimeter, the accuracy of determining E, CF^E and $Cp(3)^E$ is improved in the same way as for the InLight dosimeter.

3. Quick method based on the relationship between eye lens dose and exposure duration

Due to limited time, we just applied the first (b.1) and second (b.2) methods to investigate eye lens dose. The survey was conducted for 8 physicians and 4 technicians during 10 weeks (office hours only). During the survey, it was found that among the factors affecting eye lens dose that could be retrieved from the computer system in the cath lab, the relationship between the real–time irradiation and eye lens dose were the best metrics for assessing occupational dose to staff after each procedure (Fig.5). Because occupational dosimeter readout is usually performed quarterly, this method can provide an overview of the circumstances in incident investigation.

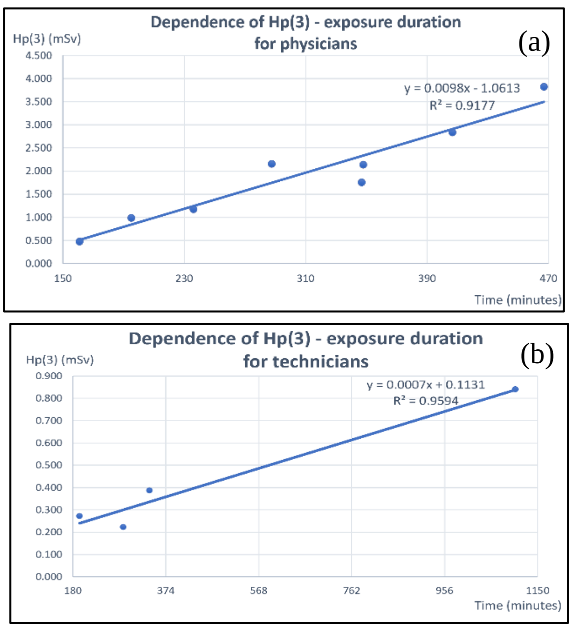

Fig. 5. Eye lens dose – exposure duration for the physicians (a) and technicians (b)

Thus, the eye lens dose of the physicians and interventional technicians is assessed based on the irradiation time (in minutes) saved on the system after each interventional procedure:

A. For interventional physicians:

$$Hp(3) = 0.0098 \times t - 1.0613 \text{ (mSv)} \quad (5)$$

B. For interventional technicians:

$$Hp(3) = 0.0007 \times t + 0.1131 \text{ (mSv)} \quad (6)$$

Where t is the exposure duration (minutes).

It should be noted that this method is applicable for a specific machine and cath lab configuration only.

III. RESULTS AND DISCUSSION

Some results of eye lens dose assessment for physicians and technicians by direct and indirect methods mentioned above are shown in Fig.6. The results have 2 main points as follows:

This method's overall uncertainty after taking into account the main influence factors (energy relative response dependence, calibration error, air kerma to personal operational dose equivalent factor estimation, detector reading) is 18.5%. This is suitable for the ICRP's recommendation [15] on overall accuracy (i.e., an uncertainty interval of -33% to +50%). In our preliminary survey, the results from the direct method (Fig.6) showed that the physician's highest left eye lens dose in 10 weeks was 3.825±0.708 mSv; for technicians, it was 0.838±0.155 mSv, which was only part of their routine work. The eye lens dose is estimated over 50 standard working weeks about 19.125±0.708 mSv/year for physicians. As mentioned above, this survey was conducted in office hours only. Therefore, if full-time monitoring (out-of-office hour emergency) is performed, the eye lens dose of the interventional physician possibly exceeds the dose limit of 20 mSv/year recommendation specified in the legal documents.

There are 2 special cases (A and D) where the eye lens dose measured by the indirect method was lower than the direct one

Tab. IV. The discrepancy of physician's Hp(3) between direct and indirect method

Case	Hp(3) (mSv)				Discrepancy (%)
	Direct method	SD	Indirect method	SD	
B	2.846	0.527	3.790	0.701	33.17
C	2.165	0.401	2.675	0.495	23.56
E	1.761	0.326	1.950	0.361	10.73
F	1.176	0.218	1.505	0.278	27.98
G	0.989	0.183	1.895	0.351	91.61
H	1.481	0.274	1.550	0.287	4.66
Average					31.95

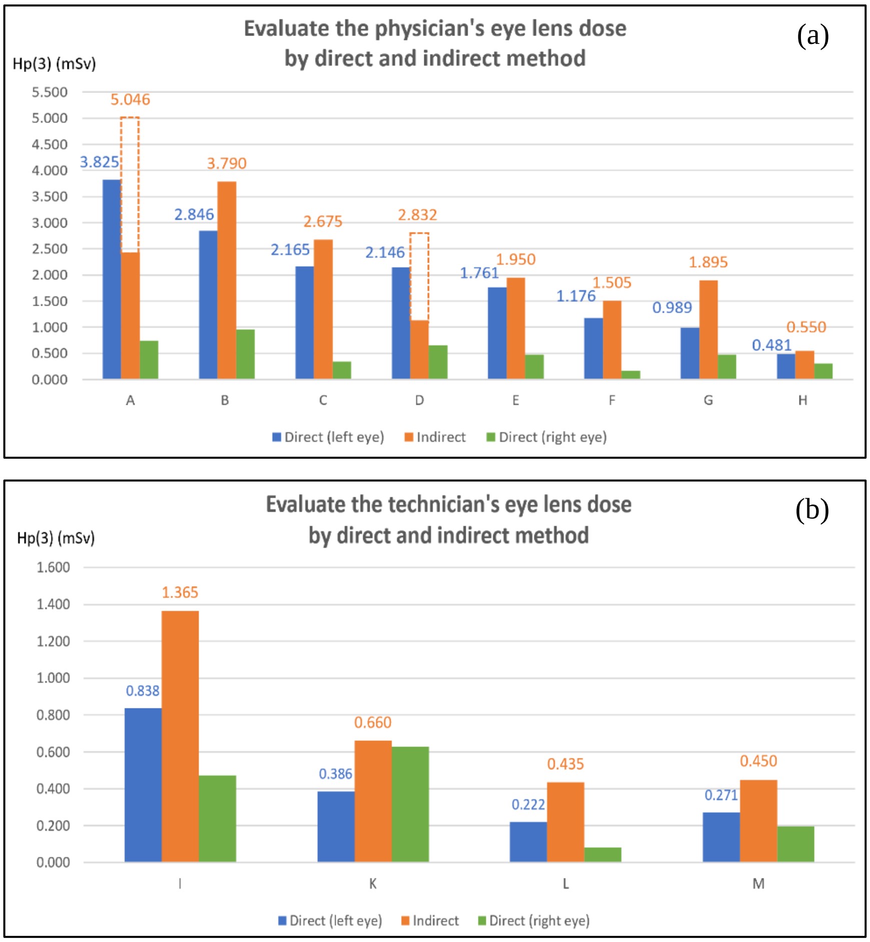

Fig. 6. Correlation between physician's (a), technician's (b) eye lens dose measured by the direct and the indirect method

due to the incorrect position of dosimeters and lead apron that the supervisor could not detect during the procedure. After 4 weeks, the dose difference was large enough to be detected and corrected in the following weeks. When a discrepancy between the eye lens dose value measured by the direct and indirect methods in the remaining cases was calculated, we have found this value of about 31.95% (average in the remaining 6 cases at the physicians). To choose the direct method as a benchmark for comparison, the eye lens dose range is from 19 – 25 mSv/year. Therefore, the eye lens dose is estimated for 30 years of work up to 600 – 750 mSv. By comparing this value with the threshold dose of 500 mSv, cataracts are possible.

III. CONCLUSIONS

Our study shows the capability to develop different methods for determining the exposure eye lens dose. Some points should be noted as follows:

1. The indirect method using an InLight dosimeter tends to overestimate the eye lens dose, but it is still useful for low-risk subjects. In this case, we need to consider the position between the two dosimeters above and below the lead apron.

2. The direct method using a nanoDot dosimeter has the highest accuracy among the three methods. It can be used for high-risk subjects such as interventional cardiologists.

3. The quick method based on the relationship between eye lens dose and exposure duration can help the managers have an overview in case an immediate dose assessment is needed.

Further studies can be based on the ways just mentioned and take into account the influence factors of the measurements, such as the type of procedure, the standing position and expertise of the physician, and the angle of scattering to the dosimeter. In addition, a future research can be more comprehensive in designing eye lens dosimeters based on nanoDot dosimeters with the multi-filter technique to ensure comfortable wearing for medical staff and more convenient monitoring. Through this study, we have some recommendations as follows: hospitals should have policies to improve and disseminate safety culture and the perception of radiation risk among their staff; employees must seriously wear the dosimeters for a more accurate assessment; dosimetry results must be disclosed to interested parties or individuals, and warn when the cumulative dose over a working life will be likely hit a threshold dose to adjust work distribution. What's equally important is that the regulatory body take measures to protect the rights and legitimate interests of subjects to eye lens dose monitoring, develop consistent technical regulations for eye lens dose assessment among hospitals, and classify which groups of subjects need closer monitoring of risk radiation exposure to the eye to ensure employee safety and improve management mechanisms.

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